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Evaluating Alternative Symbolologies for Decluttering Geographical Displays

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EXECUTIVE SUMMARY

Reducing the clutter on geographical displays should help military decision-makers manage their attention and concentrate on the most important or threatening tracks. This report presents a study that considered the question of how the decluttered tracks should be represented.

The declutter symbols must simultaneously reduce distraction while still supporting situation awareness. We used a visual search task to evaluate six declutter symbologies. The symbologies were created by manipulating two factors, symbol type and coloring. The symbol types were relatively complex MIL-STD-2525B symbols that coded substantial information about the tracks, simplified outlines of ships and aircraft that coded an intermediate amount of information, and simple dots that coded minimal information. The coloring factor consisted of using either faded versions of the MIL-STD-2525B colors or using gray. We also investigated the effect of different amounts of declutter, from no declutter to 25% declutter, 50% declutter, and 75% declutter.

The participants were 52 undergraduate students from local universities. Participants searched for two target symbols among a field of 48 symbols that were a mixture of fully visible, brightly colored MIL-STD-2525B symbols and decluttered symbols. The targets always appeared among the fully visible symbols, and the decluttered symbols merely served as distracters. Each increase in the amount of declutter produced a significant and linear drop in search time. The intermediately complex symbol outlines produced the least distraction and the fastest search times, but the differences among symbol types were small. Surprisingly, the faded colored symbols produce as little distraction and as fast search times as the gray symbols. We concluded that the faded, colored MIL-STD-2525B declutter symbols are the best declutter symbols because they are little more distracting than the alternatives while providing much more information. The next step will be to determine how well these declutter symbols help decision-makers manage their attention under more realistic conditions.

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INTRODUCTION

Theaters of operation are busy environments, and geographical displays of tactical situations can quickly become congested and cluttered by large numbers of symbols for military assets such as aircraft and ships (called tracks). Severe clutter can have the following deleterious effects:

1. Important information may be obscured or masked.
2. Irrelevant information may receive undue attention.
3. Responses may be delayed.
4. Cognitive workload may escalate needlessly.

Our goal is to develop software tools that help users manage their attention so that they can concentrate on the most important or threatening tracks and spend less attention on the less important tracks.

A common method for helping warfighters cope with clutter and manage their attention is to filter the less important tracks on the display. A number of tools exist for this method, but their underlying algorithms for determining which tracks to filter tend to be simple classification rules, such as filter all air tracks or all unknown aircraft with an altitude under 10,000 feet. These simple rules can be awkward to apply and tend not to meet the needs of sophisticated users. Nonetheless, several studies have shown that users appreciate and benefit from even simple filtering methods (Nugent, 1996; Osga and Keating, 1994; Shultz, Nichols, and Curran, 1985).

Recently, we have begun to investigate the possibility of applying artificial neural network technology to the clutter problem by training an artificial neural network to mimic the threat assessment ratings produced by expert naval personnel and then “decluttering” the geographical display based on that threat rating. This approach offers the possibility of decluttering on a much more sophisticated and operationally relevant, albeit complex, criterion. Marshall, Christensen, and McAllister (1996) showed that a simple feed-forward neural network could reliably mimic experts’ level of interest in different tracks taken from realistic simulations of naval air warfare. The neural network was given a set of 15 track features, such as altitude, speed, and country of origin for a particular track, and trained to produce the experts’ rating for the track’s level of interest on a scale of 1 to 3 for ignore, watch, and take action. The mean proportion of agreement between the model’s responses and the experts’ responses was 0.98. Importantly, the model also generalized very well to novel tracks. In sum, the neural network model captured an important early step in the experts’ decision-making process, namely, the reliable separation of tracks that can be safely ignored from tracks that pose possible problems or potential threats.

We can apply this research to the declutter task by having a trained neural network sweep over a geographical display every second, evaluating each track for its level of interest, in terms of its threat to own ship. The resulting level of interest scores could then be used to safely declutter the less interesting tracks from the display. Figure 1 shows a geographical display of the type often used in military operations. All tracks are shown using a new standard symbology for military displays called MIL-STD-2525B (Department of Defense, 1999). Figure 1 shows a cluttered geoplots on the left and a decluttered version of the same geoplots on the right. In the decluttered version, more threatening

tracks are given bright yellow symbols while less threatening tracks are given faded yellow symbols. Friendly, own force tracks are given blue symbols.

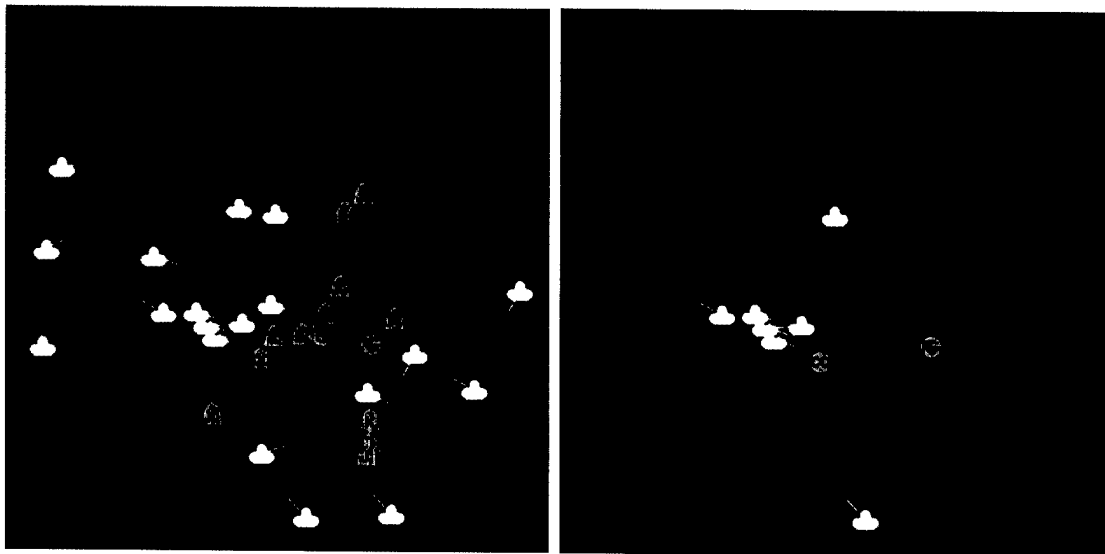


Figure 1. Cluttered geographical display (left) and same display in which less-threatening tracks have been decluttered by fading their symbols (right).

It seems clear from Figure 1 that the declutter operation helps users to focus on the more threatening tracks, but how effectively? Supporting attention management on cluttered displays as a situation evolves is a complex problem. The following issues must be resolved to make the declutter operation effective:

1. Declutter assessment algorithm and its reliability.
2. Declutter symbology.
3. Change awareness.
4. Trust and use of algorithm.

In this report, we consider the issue of declutter symbology. What should the decluttered symbols look like? Before considering the attributes of different potential declutter symbologies, however, we review the features of the MIL-STD-2525B symbols and the information they convey. Each track is assigned an affiliation based on its assessment as “friend” or “foe.”

- Friendly tracks, those from own and allied forces, are blue and assigned a round shape.
- Hostile tracks are red and assigned a diamond shape.
- Neutral tracks, such as commercial shipping vessels, are green and assigned a square shape.
- Tracks with an unknown affiliation are yellow and given an amorphous shape.

The specific shape of each track symbol is further modified according to its category, that is, whether it is an aircraft, a ship, or a submarine. The shape for air tracks is truncated at the bottom. The shape for subsurface tracks is truncated at the top.

Tracks are also assigned an interior symbol to code the type of platform, such as cruiser, aircraft carrier, fighter, or helicopter. These symbols may be icons (a bow-tie shape for a helicopter) or letters (an F for fighter). If the platform is unknown, the interior of the symbol is left blank.

Finally, a course leader codes the heading or course of a track. The course leader is a short line emanating from the center of the track in the direction the track is heading. In sum, existing MIL-STD-2525B symbols code for affiliation, category, platform, and course.

A declutter symbology must satisfy two competing demands. First, it must minimize distraction from the fully visible symbols so that users can concentrate most of their attention on the more threatening tracks. Second, the declutter symbology must continue to present information about decluttered tracks so that users can maintain situation awareness about the entire situation. Different symbologies trade off differently against these demands (Figure 2). Replacing decluttered tracks with gray dots, for example, should minimize distraction from fully visible symbols, but provide less information about the decluttered tracks. A gray dot can convey that a track is present at a given location, but it cannot convey heading, affiliation, or platform. At the other extreme, faded, colored MIL-STD-2525B symbols convey as much information as the fully visible symbols, but they are visually much more complex than dots and may create substantial distraction and increase cognitive workload. Users might not be able to easily segregate fully visible symbols from faded symbols, thereby minimizing any potential benefit from the declutter operation. Symbicons (Smallman, St. John, Oonk, & Cowen, 2001) offer a representation of intermediate complexity. A Symbicon consists of a simplified outline of an aircraft or ship combined with the symbolic interior of a MIL-STD-2525B symbol. The outline quickly conveys the category and heading of a track, while the symbolic interior conveys the platform. To create a declutter symbol, we borrowed only the simplified outlines: an arrowhead for aircraft and a boat shape for ships.

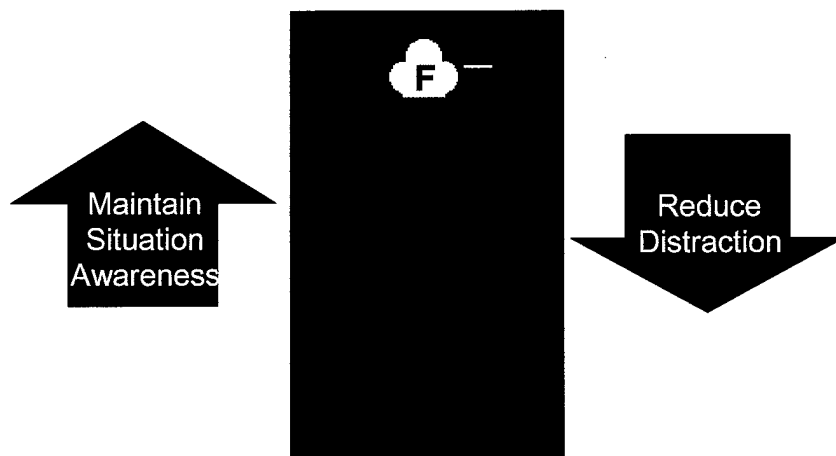


Figure 2. Six declutter symbologies and their hypothetical effects on situation awareness and distraction. The yellow symbol at the top is a fully visible MIL-STD-2525B symbol.

This report presents a visual search experiment to evaluate the distractibility of these alternative declutter symbologies. Participants saw a field of 48 symbols, and they were asked to search among only the fully visible tracks to find target symbols. We asked three questions:

1. How distracting are the three declutter symbologies: MIL-STD-2525B, Symbicons, and dots?
2. How distracting is color?
3. How does the percentage of decluttering affect performance?

Our first question was how distracting are the three declutter symbologies: MIL-STD-2525B, Symbicon outline, and dots? The MIL-STD-2525B symbols may cause substantially more distraction than dots due to their greater visual complexity. Further, the similarity of the MIL-STD-2525B decluttered symbols to the fully visible symbols may cause substantial distraction. On the other hand, the differences between some or all of the declutter symbologies and the fully visible symbols may make them easy to segregate and lead to little distraction.

Our second question was how distracting are colored declutter symbols compared with gray declutter symbols? Color is a very salient cue. For example, in a visual search task, specifying the color of a target reduces the probability of fixating non-targets more than specifying the size of a target (Williams, 1966), and color coding produces faster visual search than shape coding (Kopala, 1979; Saenz and Riche, 1974). Will colored declutter symbols prove to be too distracting, or will the fading of the decluttered symbol color provide a great enough distinction to allow users to segregate the symbols effectively?

Our third question was how does the percentage of decluttered tracks affect performance? We tested four levels of declutter: (1) no tracks decluttered, (2) 25% of the tracks decluttered, (3) 50% of tracks decluttered, and (4) 75% of tracks decluttered. Increasing the percentage of decluttered tracks decreases the set of fully visible tracks to be searched for targets, so search times should decrease. However, since the distracters remain visible in some form, they may continue to distract from the fully visible symbols. Perhaps these distractions will build up and we will observe decreasing benefits of additional levels of declutter. On the other hand, perhaps some minimum level of declutter is necessary before any benefits will be seen. If the decluttered symbols are truly minimally distracting, then the benefits of additional decluttering should be linear.

METHOD

PARTICIPANTS

The participants were 52 undergraduates from local universities who were paid for their participation. Data from one participant was discarded due to data collection problems.

STIMULI

There were 19 conditions in the experiment. These conditions were created by crossing three declutter symbologies (MIL-STD-2525B, Symbicons, and dots) by two colors (colored and gray) by three declutter percentages (25, 50, and 75%) plus a no declutter baseline condition. Each participant saw all 19 conditions. There were nine trials for each condition. Trials were blocked by condition. The order of conditions was balanced across participants. The trials were presented on a 15-inch color monitor with a resolution of 1024 x 768 pixels.

Each trial consisted of a display showing a target and a "map" of 48 tracks (Figure 3). Each track was composed of one of eight platforms (bomber, fighter, helicopter, missile, carrier, cruiser, submarine, or tanker), one of four affiliations (friendly, neutral, unknown, or hostile), and one of four headings (north, south, east, or west). The tracks were divided into fully visible and decluttered tracks. The fully visible tracks were represented as MIL-STD-2525B symbols.

The percentage of decluttered tracks varied by condition: no declutter in which no tracks were decluttered, 25% declutter in which 12 tracks were decluttered, 50% declutter in which 24 tracks were decluttered, and 75% declutter in which 36 tracks were decluttered. The representation of the decluttered tracks varied by condition.

To create the colored declutter symbols, the saturation and luminance of the fully visible colors were reduced to one third of their initial values. To create the gray decluttered symbols, the luminance remained at one-third and the saturation was reduced to zero. Two symbols were used to create the Symbicon outlines: an arrowhead for all aircraft and a boat shape for all ships. The Symbicon outlines did not distinguish between specific platforms. The orientation of the shape conveyed heading. Colored and gray decluttered Symbicons used the same colors as the colored and gray decluttered MIL-STD-2525B symbols. Colored and gray decluttered dots were also created using the same colors. The dots did not code platform or heading.

The target for each trial was shown on the left side of the display. Targets were generated randomly from the set of eight platforms, four headings, and four affiliations.

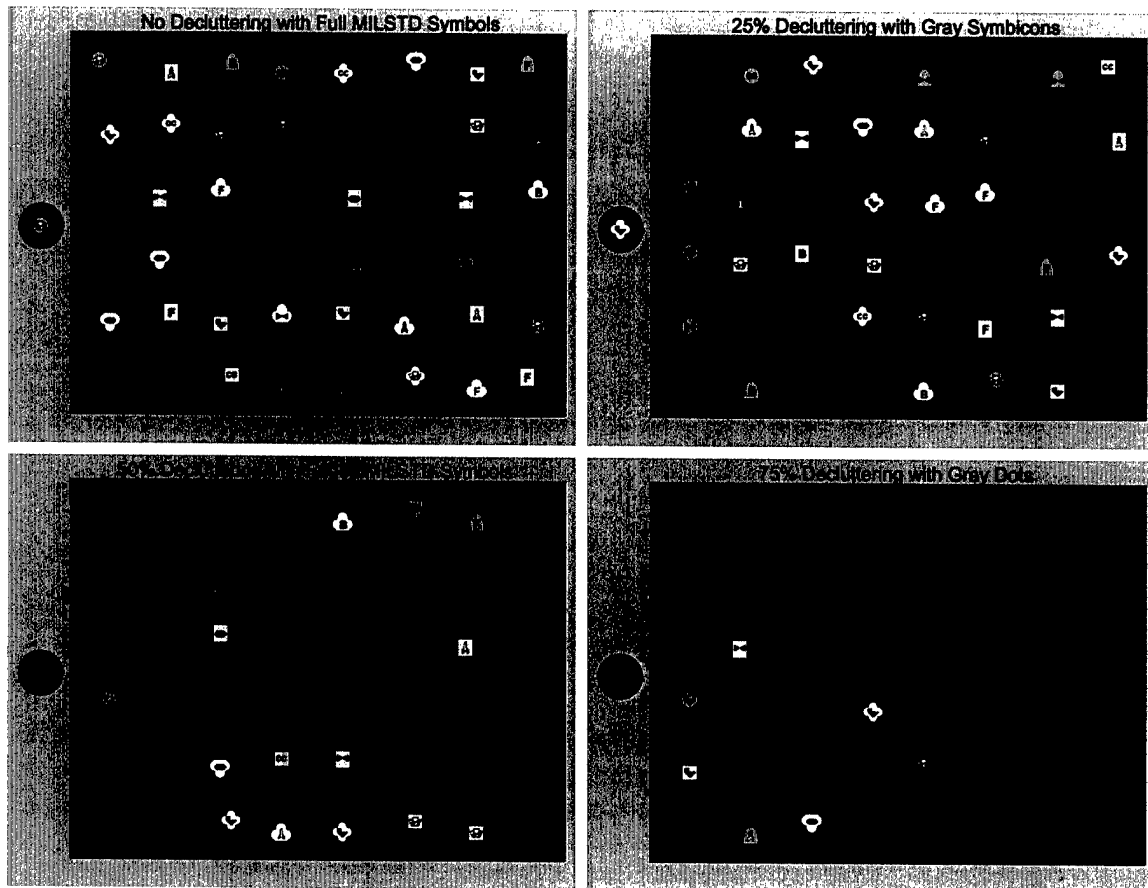


Figure 3. Four screenshots of experimental display: no declutter (upper left), 25% declutter using gray Symbicons (upper right), 50% declutter using faded MIL-STD-2525B (lower left), and 75% declutter using gray dots (lower right). The target appears in isolation on the left of each map.

The 48 tracks on the map for each trial were also generated randomly, subject to a set of restrictions. First, three “near distracters” were created by changing one of the three features of the target. Second, 18 “medium distracters” were created by changing two of the three features. Finally, the remaining 25 “far distracters” were created by changing all three features. Track generation was balanced so that there were equal numbers of each platform, heading, and affiliation.

Decluttering was accomplished by randomly picking tracks according to the percentage of declutter for the condition. Only medium and far distracters could be decluttered, and the decluttered distracters were always in a ratio of three far to one medium distracter. For the chosen declutter tracks, their MIL-STD-2525B symbols were replaced by the appropriate symbology for the condition. The 48 fully visible and decluttered tracks were randomly arranged on the map, subject to the constraint that targets be separated by at least one intervening distracter.

PROCEDURE

Participants were initially introduced to the visual search paradigm and the features of the symbols. However, participants were not instructed or expected to know the meanings of the platform symbols. Participants were introduced to each specific condition as it occurred during the experiment by performing a demonstration trial.

Each trial began by presenting the target next to a blank map for 2 seconds. After this "encoding interval," the 48 tracks appeared on the map and the timer started. When participants found a target on the display, they moved the mouse cursor, which appeared as a white circle, over the chosen track and clicked the mouse. If the choice matched the target, the computer played a tone to indicate a correct response, and a red circle appeared around the choice to mark the track. Participants then continued searching for the second target. If the choice did not match the target, the computer played an incorrect tone, and the trial continued. Once the second target was found, the trial ended, and the computer immediately advanced to the next trial. Search times were recorded for both the first and second matches.

The entire experiment took approximately 45 minutes to complete, including one break about half way through.

RESULTS AND DISCUSSION

Figure 4 shows the search time for both targets. These times were submitted to a 3 symbology by 2 color by 3 declutter percentage within participant analysis of the variance (ANOVA). The no declutter (0%) baseline condition was not included in the analysis. Increasing the percentage of decluttered tracks led to significantly faster search times, $F(2, 100) = 80.9$, $p < 0.0001$. Each increase in the declutter percentage led to significantly faster search speeds (p 's $< .05$ by post hoc tests). Each increase, including the increase from 0 to 25% was approximately 0.5 seconds. This linear increase suggests that decluttering provides an immediate and increasing benefit for each additional track decluttered. Decluttering does not have to reach some threshold before it is valuable or after which its value diminishes.

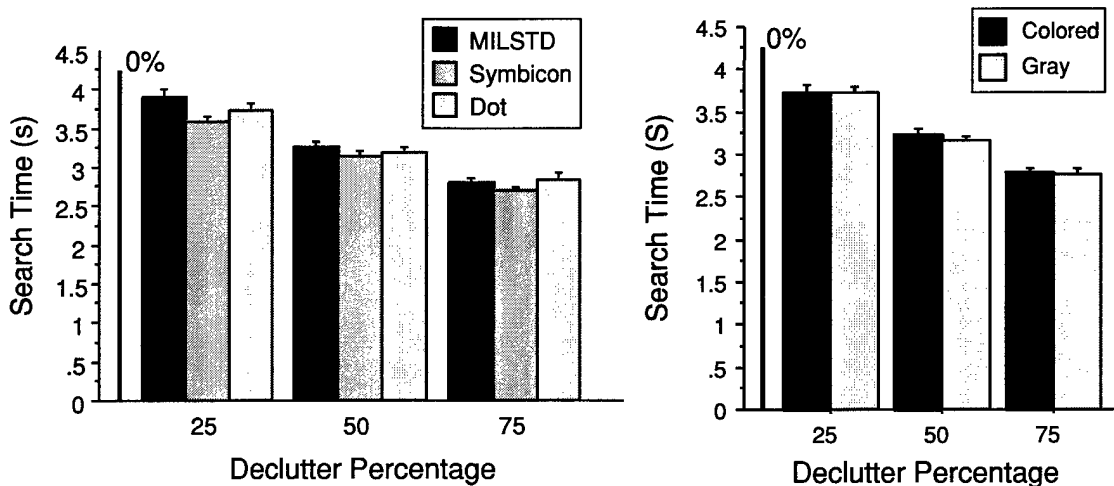


Figure 4. Time taken to find both targets on each trial. Graph on left shows effect of declutter symbology on search time for each level of declutter. Graph on right shows effect of declutter color on search time for each level of declutter.

The symbologies also produced significantly different search times, $F(2, 100) = 6.2$, $p = 0.003$. The Symbicons produce significantly faster search times than the MIL-STD-2525B symbols (by post hoc test). This finding suggests that the Symbicons were less distracting than the MIL-STD-2525B symbols. The difference, however, was small (0.18 seconds). It is somewhat surprising that the dots did not produce the least distraction and therefore the fastest search times. However, it may be that the small dots had a tendency to cause participants' eyes to "swim" somewhat because of the moderate regularity of the distribution of tracks on the display. As a practical matter, the lack of large differences suggests that MIL-STD-2525B declutter symbols are no more distracting than simpler symbologies while retaining much richer information about the decluttered tracks. MIL-STD-2525B declutter symbols are therefore preferred.

Color did not produce significantly different search times, $F(1, 50) = 1.09$, $p = 0.31$. Gray decluttered tracks were no less distracting than colored decluttered tracks. This non-effect is surprising and interesting because color is such a salient feature of stimuli. Apparently, participants

were able to easily segregate the faded, colored declutter tracks from the brightly colored fully visible tracks. Again, as a practical matter, the lack of a difference between colored and gray decluttered symbols suggests that faded colored symbols are no more distracting than gray symbols while retaining more information about the decluttered tracks. Faded, colored declutter symbols are therefore preferred.

CONCLUSIONS

The main purpose of this study was to determine which type of symbology would work best for decluttering a geographical display. The two competing requirements for declutter symbols are to reduce distraction from the fully visible symbols while providing information about the decluttered tracks.

The faded, colored MIL-STD-2525B symbols appear to satisfy these requirements best. They clearly provide more information since they code for all the information that the fully visible symbols code, including platform, category, affiliation, and heading. Nevertheless, they appear to be only marginally more distracting than the simpler Symbicon outlines and dots.

Perhaps most surprisingly, the faded colors of the MIL-STD-2525B declutter symbols and the faded colors of the Symbicons and dots were not any more distracting than their gray alternatives. Despite the salience of color as a cue in display design, it appears that fading the symbol colors made them sufficiently different from the fully visible symbols. Participants easily segregated and ignored the colored declutter symbol during this search task. Nonetheless, the faded, colored MIL-STD-2525B declutter symbols remain clearly visible (Figures 1 and 3).

Finally, each declutter symbology that we tested provided a linear decrease in search time as the percentage of decluttered tracks rose. This finding indicates that decluttering a display, at least in a search task, can be useful even at low levels of declutter, and its effectiveness increases with increasing declutter.

As an operational consideration, we think that users should be able to select decluttered symbols and have them become fully illuminated while they are selected. We also think that users should be able to turn the decluttering operation on and off or adjust the level of decluttering as their needs change. Much work remains to be done to make the decluttering operationally successful. This study revealed that decluttering can be useful for reducing search time and allowing users to focus on a designated subset of tracks. It also showed that faded, colored MIL-STD-2525B symbols, despite their complexity, are a suitable choice for the declutter symbology.

Further evaluation of the declutter symbologies is underway. In our next study, we plan to measure eye movements during this visual search task. This study of eye movements will allow us to investigate much more closely how the displays are searched and which declutter symbols continue to attract attention. We also plan to use a measure of cognitive effort based on pupil dilation (Marshall, 2002) to investigate how decluttering might affect cognitive effort on the task.

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